SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, WERNER BLOHM of Reddersenstrasse 67, D-28359 Bremen, Federal Republic of Germany, HARALD SIKORA of Katrepeler Landstrasse 70 A, D-28307, Federal Republic of Germany and ADRIAN BEINING of Worthkoppel 27, D-27367 Bötersen, Federal Republic of Germany, all German citizens have invented certain new and useful improvements in A METHOD FOR MEASURING THE DIAMETER OF AN ELONGATED ARTICLE OF A CIRCULAR CROSS SECTION of which the following is a specification:

.../2

BACKGROUND OF THE INVENTION

The invention relates to a method for measuring the diameter of an elongated article, in particular a cable of a small diameter, according to the preamble of patent claim 1.

It is known to determine the diameter of cables or other elongated articles in an optical way in that it is irradiated with the light of a light source, wherein the main beam direction is approximately perpendicular to the longitudinal axis of the article. On the opposite side the light under the application of refracting surfaces (lenses, objectives, etc.) is projected onto a cellular light-sensitive sensor, wherein the measured object casts a shadow onto the line sensor. The shadow borders are acquired; their distance is a measure of the diameter.

With the practical application of the known device it is hindered by contaminations at the light entrance openings and light exit openings. It is therefore also known to so select the optic that at the light entrance and light exit openings the light becomes defocussed. Partial contaminations influence the measurement then only in a limited manner.

The known optical devices function in principle in a satisfactory manner, but are however relatively complicated and have a large construction.

BRIEF SUMMARY OF THE INVENTION

It is therefore the object of the invention to specify a method for measuring the diameter of an elongated article which in cross section is approximately circular, in particular of an artery or of a cable of a small diameter, which succeeds with little

.../3

expenditure, yet brings with it very exact results, although the article changes in its position transverse to its longitudinal extension within limits.

This object is achieved by the features of patent claims 1 and 2.

With the method according to the invention the article is irradiated with the fan-shaped beam of a monochromatic dot-shaped light source. The intermediate connecting of optical elements between the light source and the article and the sensor may where appropriate be done away with. A bundling, parallelising or other influencing or deformation of the beam may be done away with. The shadow of the article is projected onto a linear light-sensitive sensor of a construction type known per se. For example a so-called CCD-line may be used which comprises approx. 2048 individual light-sensitive elements at a distance of 14μm. Such a sensor has a high resolution.

It is to be understood that also a multiple-line sensor (surface sensor) of a suitable resolution may be applied. The lines thereof are then evaluated separately.

The measured signals caused by the diffraction give conclusions on the position of the diffracting edge in the measuring space. This is exploited by the invention. On account of the appearances of diffraction e.g. the geometric shadow borders do not directly result from the course of intensity of the irradiation incident on the sensor, but rather they must be derived from the diffraction margins which set in. This may be evaluated by a comparison to a course $f(\xi)$ of the intensity in the diffracting margin known from the theory of Fresnel diffraction. With this the argument of the function $f(\xi)$: $\xi=f(x-x_{geo})$ applies. The course of intensity in the diffraction margin with a predetermined distance of the diffracting edge to the receiving sensor is selected e.g. as a standard course (base course) with the extension d=1. This is because a mathematical description of the intensity course is not possible without further ado. The free parameter d (extension of the basis course $f(\xi_o)$) and x_{geo} (searched geometric shadow border = displacement of

.../4

the base course $f(\xi_o)$) are varied for so long until an optimal correlation between $f(\xi)$ and the course of the intensity in the measured diffraction margin sets in.

Alternatively also sample courses $f(\xi_1)$, $f(\xi_2)$, ... $f(\xi_N)$ may be derived from discrete values for d and x_{geo}, in order then to be brought to coincide with the intensity course in the measured diffraction margin (sample comparison).

A further possibility according to the invention lies in using only a few characteristic feature points in the diffraction margins (e.g. turning points and/or local intensity minima and maxima) for determining the geometric shadow borders. The position of the feature points in the intensity course of the diffraction margin is characteristic for the position of the diffraction edges in the measuring space, e.g. for those of the shadow borders. Also the gradient between feature points of the intensity course e.g. in the region of the geometric shadow borders (e.g. up to the first maximum) permits the determination of the diameter or the position of the geometric shadow border.

With fan-like expanding light irradiation for determining the article diameter from the geometric shadow borders, the knowledge of the distance of the measured object perpendicular to the line sensor is necessary. The position of the article transverse to its longitudinal extension during the measurement may indeed change. This is e.g. the case with cables during the movement from the place of production to a winding device. At the same time not only the does the distance of the shadow borders change on account of the beam, but rather on the outer contour of the article also the position of the edges causing the diffracting changes. Specifically these edges lie where two beams being emitted from the light source contact the outer contour on the left and right in the form of tangents. Both diffracting edges as a result lie on a chord of the article cross section assumed as circular. This chord may be caught as a replacement aperture. The nearer the article lies to the light source the further is this replacement

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aperture distanced from the circle centre of the article cross section. For taking this effect into account likewise the knowledge of the distance is of significance.

The mentioned distance may also be evaluated from the course of movement. The extension d as well as also the distance between characteristic feature points in the diffraction margin represent a measure for this.

Generally the determining of the distance of the measured objective relative to the line sensor may also be effected also with the aid of any additional measuring means. Preferred is the application of a second identical measuring system, consisting of a point-shaped monochromatic light source and a line sensor with a measuring axis which lies perpendicular on the measuring axis of the first measuring system. Principally also more than two measuring systems may be applied. Thus roughly three systems may be positioned to one another at angle of 120° in each case.

Further, essential to the invention is that the geometry of the fan-shaped light beam, the distances from the light source, article and sensor as well as the diameter region of the article may always be selected such that the diffracting effects from the edges of the article lying opposite one another do not mutually interfere in the plane of the sensor.

The method according to the invention requires an extraordinarily less complicated measuring system. Lenses, objectives or similar optical elements which are always the source of imaging errors, blurring, etc. may where appropriate be done away with. Since no imaging errors occur on account of the known mathematically exactly describable physics of the diffraction appearances, a highly precise determination of the diameter is possible. Furthermore a further advantage lies in the fact that the measuring system on account of the elimination of refracting surfaces is constructed extraordinarily small. It may however be advantageous to provide an optical arrangement between the light source and the article, which permits a reduction of the

.../6

distance between these objects. By way of this the measuring device is constructed even smaller.

Contaminations in the region of the measuring system by their nature lead to erroneous measurements. These may be reduced in that the optical active zone of the light source parallel to the longitudinal axis of the article has a certain extension, i.e. is linear whilst perpendicular to this it remains a point projector as before. If e.g. a diode laser for the measurement according to the invention in the optically active zone has a height in the picture plane of approx. 3 μm then its length, i.e. the extension perpendicular to the picture plane is e.g. 0.5 mm.

Analogously the extension of the individual elements of the light-sensitive sensor parallel to the longitudinal axis of the article may be selected significantly larger than in the axis direction of the line sensor. Contaminations on the light source or the sensor do not make themselves so noticeable in the same interfering manner as they would occur with a purely point-shaped design of the light source and sensor element. By way of the assessment according to the invention as a result a type of defocussing effect is produced.

Partial contaminations on the light source, for example of a laser diode, of a convergent lens or on the picture sensor, likewise cause diffracting effects which appear as diffracting pictures on the sensor. It is to be noted that the frequency spectrum of the intensity fluctuations caused by the diffracting is higher the closer is their location of origin to the sensor. Contaminations on the sensor cause extreme high-frequency intensity fluctuations whilst those on the irradiation source have the effect of low-frequency fluctuations. The intensity fluctuations from the object to be measured caused by diffractions have as a result a frequency spectrum which lies between these extremes. According to the invention a filtering of the measured intensity course is effected by the sensor in a manner such that if possible only one frequency spectrum is

.../7

reached for evaluation, which is caused by the diffracting of the article. If with the device for carrying out the method the dimensions are selected such that also with the application of protective glasses on the one hand between the irradiation source and the object to measured and on the other hand between the picture or line sensor and the object to be measured, frequency spectrums which can be differentiated arise, then with the help of a suitable filter method also with a partial contamination in the measuring device a reliable measurement may be carried out.

It is further to be noted that the extension factor d of the diffraction margins and as a result also the distance between characteristic feature points is smaller the closer the diffracting edge lies to the receiver sensor. The evaluation of only such diffraction margins, whose extensions d are relevant for the valid positions of the measured object, thus reduces the dirt sensitivity and thus permits a more reliable measurement. If only characteristic feature points are evaluated, then from the distance between consecutive points it may be deduced whether the measured diffraction space is caused by the measured object or from e.g. contamination in the measuring path.

If instead of a single point projector several are applied which either are tightly packed or have a more or less large distance to one another, and if these are operated alternately, it is possible to extend the measuring region. Likewise by way of a suitable evaluation of the intensity courses brought out on the sensor line by the respective point projectors, the sensitivity to dirt may be reduced. In the individual courses specifically there appears a different local shifting between such courses of diffraction, which are brought out by objects in the valid measuring zones, and those which result from (dirt) objects located outside this region.

Also the individual intensity courses on the lines of multi-lines sensors may be exploited for reducing contamination influences. For example that line may be selected

.../8

for determining the geometric shadow border with which no or the smallest contamination is detected.

Additionally to the "electronic" measures for reducing the dirt-sensitivity or also alternatively means may be provided in order to minimise the influence of contaminations on the measuring system. Thus for example between the laser and the measuring object two distanced slot arrangements may be provided between which an electrode for an electrostatic "suctioning" of dust or other contaminations is arranged. In the same manner between the measuring object and the line sensor an electrode may be provided. In this case the slot arrangements then lie at earth. Another possibility may lie in continuously producing an excess pressure in the measuring space which prevents contaminations from entering into the measuring space. A third possibility lies in setting up a rinsing charge in the measuring space or on the parts at danger from contamination. For example an air pressure charge is applied.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is hereinafter described in more detail by way of drawings.

Fig. 1 shows schematically a measuring device for carrying out the method according to the invention.

Fig. 2 shows idealised the intensity course on the irradiation receiver according to Fig. 1.

Fig. 3 shows a modified device for carrying out the method according to the invention.

Fig. 4 shows a third embodiment form of a device for carrying out the method according to the invention.

Fig. 5 shows a fourth embodiment form of a device for carrying out the method according to the invention.

Fig. 6 shows the device according to Fig. 5 rotated about 90°.

Fig. 7 shows a fifth embodiment form of a device for carrying out the method according to the invention.

Fig. 8 shows a device according to Fig. 7 rotated about 90°.

Fig. 9 shows an embodiment form with electrostatic removal of dirt particles from the viewing region of the measuring system.

Fig. 10 shows the embodiment form shown in Fig. 9 from above.

Fig. 11 shows a further embodiment form, in which the dirt particles are removed from the viewing region of the measuring system by air-rinsing.

Fig. 12 shows a similar representation as Fig. 9 with a slight modification.

Fig. 13 shows a similar representation to Fig. 10 but with a slight modification.

.../10

DETAILED DESCRIPTION OF THE INVENTION

In Fig. 1 the cross section of an elongated article, a wire or a cable 10 (subsequently as a measuring object a cable is described). It is to be understood that also any other thread-like object may be measured which extends perpendicularly to the plane of the drawing and which is moved forwards for example at 10mm/sec to 30m/sec. The device for manufacturing the cable as well as for producing its forward displacement are not shown. They are generally known. The cable has e.g. a diameter of 0.5 mm to 100 mm and more.

On the left side of the cable 10 there can be recognised a point-shaped light source 12. It may be formed by a laser diode, which e.g. produces IR light. The point shapedness results preferably in the extension which lies in the measuring plane, which is characterised by the fan-beam 14. In this direction e.g. the active zone of the laser diode 12 is 3μm wide. Perpendicular to this, i.e. parallel to the longitudinal axis of the cable 10 there may result an extension of the optically active zone of e.g. 0.5 mm.

On the side lying opposite the laser diode 12 there is indicated a line sensor 16 whose longitudinal axis lies in the picture plane and perpendicular on the main extension direction of the irradiation of the laser diode 12. The individual elements 18 of the sensor, for example of a CCD line or of an individual line of a CCD matrix have an extension in the picture plane of e.g. 12μm and a distance to one another of about 14μm. The line may, as known per se, be provided with e.g. 2048 cells or elements, if the diameter of the article is approximately maximum 15 mm.

The cable 10 produces a shadow on the line sensor, whose extension is representative of the diameter of the cable 10. The extension of the shadow is on account of the fan-shaped broadening beam path not equal to the diameter of the cable. The distance of the longitudinal axis of the cable 10 to the line sensor is therefore to be taken into

account with the measurement, and specifically in the manner that the measured shadow extension is to be multiplied with by factor (<1) derived from the beam principle. Since the replacement aperture relative to the middle point of the cable cross section likewise varies with the distance between the light source 12 and the cable 10, this dependency is likewise to be taken into account.

On the outer edges of the cable 10 the monochromatic light of the laser diode 12 undergoes a diffraction. The intensity course resulting therefrom is shown simplified in Fig. 2. The course of the geometric shadow as would set in also without appearances of diffraction is drawn in dashed and is indicated at 20. Apart from the light diffracted in the geometric shadow region left and right of the geometric shadow borders, intensity courses with slowly decaying, alternately successive intensity maxima and minima are registered. This pattern resulting on account of running time differences (interference) is called diffraction margin. The maxima setting in as a result of superposition are indicated at 24, the minima relating to deletions are indicated at 26. The frequency with which these maxima/minima follow one another is dependent on the distance between the diffracting edge and the sensor line. The intensity course in the diffraction space varies about a middle level 28 as it would set in without a measuring object.

The geometry of all objects taking part with the measuring arrangement is such that the diffraction margins do not influence each other in a mutually interfering manner.

The intensity course as is to be recognised in Fig. 2 is in its shape as well as its length on the receiving line characteristic for the position of the diffraction margin in the measuring space. The geometric shadow border on the receiving line may be determined by a comparison with theoretically determined sample courses, but may also be determined by individual characteristic feature points (e.g. turning points, intensity maxima or minima) in the diffraction margin.

.../12

A partial contamination of the laser diode 12 and/or of the sensor line 16 leads to further diffraction effects which superimpose to the curve course according to Fig. 2. An elimination of this interfering effect lies in evaluating only such diffraction margins with certain extension factors or with certain distances of the characteristic feature points. Taking into account the frequency spectrum as arises by diffraction on the cable 10 within the valid measuring zone, furthermore by way of band-pass filtering the measurement can be made less susceptible to dirt. All methods can also be applied with the application of non-shown protective glasses between the light source 12 and the cable 10 on the one hand, and between the cable 10 and the line sensor 16 on the other hand.

With the embodiment form according to Fig. 3 a light source 12a is shown which is equal to the light source according to Fig. 1. The same applies to the sensor line 16a. In Fig. 3 however there is shown a lens 30 by which means bundled light is cast onto the cable 10a. By way of this the device is reduced in its dimensions, and on the other hand the advantage is retained of having a measuring region which is larger than with the device according to Fig. 1.

It is generally known to improve the accuracy of the diameter measurement and to determine the ovalness of the article in that along two orthogonal axes a measurement is carried out. This may be effected also with a further measuring device as is shown in Fig. 4 and is provided in an arrangement rotated about 90°. In this manner then not only according to the invention can the diameter be measured at two locations but also the distance between the cable 10 and the line sensor 16 or 16b, which is subjected by nature to fluctuations on forward movement of the cable. The intensity courses in the diffraction margins on both sides of the cable shadow projected onto the receiver line are approximately cylindrical. Thus e.g. from the positions of feature points lying opposite one another mirror imaged in the left and right diffraction margin, the middle position of the projected shadow may be concluded. On the connection line between

.../13

this position and the laser diode 12 there is located the cable 10. A corresponding connection line may be construed for the measuring arrangement rotated about 90°. The intersection point of both lines represents the middle position of the cable 10 in the measuring space. Thus the distance to the respective line sensor 16 or 16a is known. The evaluation device, with which the determination of the diameter is effected, may therefore constantly be fed with these distance values, so that where necessary a correction takes place.

In the embodiment form according to Fig. 5 and 6 a cable 10c, a line sensor 16c and a light source 12 are shown. In the shown case furthermore cylinder lenses 32, 34 are provided wherein the lens 32 focuses in a line-like manner the irradiation of the light source roughly in the middle of the cable 10c in one plane. Transverse to the cable axis there results a linear extension of the fan-shaped illumination. The shadow setting in is indicated in Fig. 6 in a shaded manner.

Additionally or alternatively for the reduction of the dirt sensitivity by way of electronics, means may be provided to prevent contamination in the viewing region of the measuring system in the first place, or to eliminate this. This may for example be effected with the embodiment form according to Fig. 9 and 10 in that in the region between the laser diode 12e on the one hand and the cable 10e on the one side and between the cable 10e and the CCD line sensor 16e on the other side there are arranged slot apertures 50, 52, 54, 56 and an electrode 36 and 38 respectively. The latter lie at a high voltage. The part of the measuring device consisting of the laser 12e and the slot apertures 50, 52, or the part consisting of the slot apertures 54, 56 and the sensor line 16e may lie at earth. With the help of electrodes 36, 38 an attraction effect is exerted on dust particles. As a result dust is "suctioned out" of the actual measuring space.

A further possibility to reduce contaminations may lie in keeping the measuring spaces 51 and 53 according to Fig. 11 clean with the help of slot apertures 58, 60 and where

../14

appropriate to set them under a certain excess pressure. By way of this dust particles are prevented from penetrating into the measuring space.

Furthermore with the help of suitable nozzles in an impulsed manner air is blown into the measuring space which is indicated by arrows 40 and 42. With the help of pressure impulses contamination is driven out of the measuring space. Instead of pressure impulses also continuous gasflows may occur which carry contaminations out of the measuring space.

It is to be understood that the described measures may of course be applied in the same manner to the devices according to Figures 1 to 5. The same is the case with the device according to Figures 7 and 8 yet to be described.

The difference from the embodiment form according to the Figures 5 and 6 lies in the fact that in front of the cylinder lens 33 there is arranged a lens 44. It effects a bundling of the beam path and is in contrast to the fan-shaped beam path according to the embodiment form in Fig. 5 and 6. The advantage of a bundled beam is described in combination with the embodiment form according to Fig. 3.

The accuracy of the measuring system may be even further increased with the knowledge of the exact momentary wavelength of the light of the laser diode. The wavelength of the light may be evaluated from the diffraction margin, wherein the distance of the diffraction edge to the light source or to the sensor must be known. The diffraction edge may be that of the article to be measured or also a reference edge which is exactly positioned with regard to the light source or the sensor.

Fig. 12 shows a similar representation as Fig. 9, so that the same parts are provided with the same reference numerals. Different is merely the arrangement of the sensor 16'e which is not arranged perpendicular to the arrangement but at a certain inclination.

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The computation of the diameter way be carried out just as in the above described type and manner, wherein the oblique positioning of the sensor 16'e must be correspondingly corrected. The oblique positioning under circumstances has the advantage that a contamination is more easily prevented.

The embodiment form according to Fig. 13 is equal to that according to Fig. 10 with the exception that the cable 10'e or the artery does not extend perpendicularly to the main beam direction, but at an angle.

The embodiment form according to Figures 12 and 13 above all things are to illustrate that it is not obligatory that the artery axis must extend perpendicular to the main beam direction. This applies also to the sensor 16'e.